A ONE-DIMENSIONAL STOCHASTIC SYNTHETIC-FIELD TURBULENCE SIMULATION METHOD

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It is increasingly recognized that synthetic-field approaches to subgrid closure of large-eddy simulations (LES) may be essential for accurate treatment of the multiple, strongly non-linear microscale couplings that govern multi-physics turbulent flow processes. A synthetic-field method denoted One-Dimensional Turbulence (ODT) has been developed and extensively validated as a stand-alone turbulence model, as outlined here, and progress has been made on the implementation of ODT as an LES subgrid closure.

Robust subgrid closure based on a synthetic field must meet several stringent requirements. It must adequately represent multi-scale dynamical flow processes that are generally regarded as inherently multi-dimensional. It must capture anisotropy caused by boundary and body forcing (e.g., buoyancy in stratified flow), and flow inhomogeneity, such as near-wall flow structure. The strategy that has been adopted is to combine two approaches that, together, provide the needed capabilities.

One of these approaches is synthetic-field construction using random sequences of additive or multiplicative operations to emulate the wide range of spatial scales of turbulent flow fluctuations. This approach represents fluctuation effects in detail, and in fact is designed specifically for the study of these fluctuations. However, it contains no representation of the physical processes that drive these fluctuations, so it is useful primarily for studying the generic (universal) properties of turbulent fluctuations rather than flow-specific effects. In particular, it does not capture multi-physics couplings or structural inhomogeneities induced by initial or boundary conditions or body forces.

The other approach is based on a conventional 1D boundary-layer formulation of the fluid-dynamical equations. For application to turbulence, this formulation has previously been used to represent ensemble-averaged behavior, with the role of turbulence represented by enhancement of viscous momentum transport. At best, such an approach captures the overall transfer of momentum, mass, and heat without resolving local fluctuations that strongly influence subprocess interactions.

In ODT, turbulence effects within the 1D boundary-layer framework are not represented by enhanced diffusion. Rather, the 1D boundary-layer equations are treated as instantaneous equations. Turbulence effects are incorporated by performing a random sequence of operations somewhat analogous to the stochastic approach. Each operation is the model analog of an individual turbulent eddy. The resulting formulation captures both turbulent cascade properties, as in previous stochastic models, and the coupling of cascade dynamics to the initial and boundary conditions and forcings corresponding to various inhomogeneous turbulent flows of practical interest. Model features and performance are demonstrated by comparing results to measurements and direct numerical simulations of homogeneous turbulence, free-shear flows, wall boundary layers, buoyant stratified flows, and particle-laden flows.